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Behavior of Self Compacting Reinforced Concrete One Way Bubble Deck Slab

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Abstract

Reinforced concrete slab with plastic voids (Bubbled Deck system) is a new type of slabs which has two-dimensional arrangement of voids within the slab that is developed to decrease the slab self-weight while maintaining approximately the same load carrying capacity as compared with the solid slabs. Plastic voided slabs have the ability to reduce concrete amount by about 30 percent and this reduction is so important in terms of cost saving and enhancement the structural performance. In this research paper investigation is carried out to study the shear strength behavior of one-way bubble deck slab using self-compacting reinforced concrete. The experimental program consists of testing thirteen one-way slabs with dimensions of (1700 length, 700 width and 150 thick) mm. One of the tested slabs is a solid slab (without balls) is used as a reference, the remaining twelve bubbled slabs with ball diameter (73, 60) mm are divided into five groups according to the parameters of the experimental work, the parameters of the experimental work include: type of slab (bubble and solid slabs), ball diameter (73, 60) mm, shear reinforcement and spacing between balls. The experimental results showed that the bubbled slabs without shear reinforcement have a decrease in the ultimate load as compared to solid slab by about 3.7% to 14.3% and an increase in the deflection at ultimate load by about 10% to 22%, at the same time the first crack load decreases by about 15.3% to 42.4% as compared to solid slab due to decreases of moment of inertia of bubble slab compared to solid slab. Also, the results showed that the bubbled slabs withe shear reinforcement (multi-leg) have an increase in the ultimate load as compared to solid slab by about 35.4% to 57.3% and an increase in the deflection at ultimate load by about 1% to 15%, at the same time the first crack load decreases by about 2.8% to 27.4% as compared to solid slab.

Keywords: Self Compacting, Reinforced Concrete, Shear Behavior, Deck Slab.

1. Introduction

Slab is very important structural member to make a space in the building, it is the most member that consuming concrete. In addition, when the span of a building increases the deflection of slabs increases also. Therefore, the slab thickness is increases. The increase of slab thickness makes slab heavier and it leads to increase column and foundation size. Thus, it makes buildings consume more materials such as concrete and steel [1]. In the past various attempts have been developed to reduce the weight of concrete slab with maintaining the slab flexural strength as it was reducing the slab weight would reduce deflection and makes larger span lengths achievable. The waffle, hollow core and beam-block slab systems were and are still used to reduce the slab self-weight [2]. Bubbled reinforced concrete slab system, also known as voided slab system, has been recently introduced in Europe. It was invented by the Danish engineer, Jorgen Breuning in 1990[3]. This type of slab contains hollow plastic bubbles cast into the concrete to form a mesh of void shapes within the slab [3]. These bubbles will decrease the dead weight up to (35%) compared to a solid slab of an

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equivalent dimensions. So, the bubble deck slabs can be thinner, stronger, lighter and less price than the normal one [4]. The bubble deck slab could be a methodology of nearly eliminating of all concrete from the center of a slab that isn't playing any structural perform, therefore the dead weight would be reduced dramatically. The ineffective concrete within the center of slab are replaced by plastic balls, therefore decreasing the dead weight and increasing the efficiency of the slab and these balls result in (30-50%) lighter slab that reduces the loads on the columns, walls, foundations, and after all of the complete building [5]. However, the shear capacity of bubble deck slab is significantly less than the solid slab because the resistance is directly related with the depth of concrete [6].

Many researches deal with the bubbled slabs of different conditions. Kleinmann (2006) [7] compared solid slabs with two types of bubbled RC slabs with an equivalent depth, 340 mm. The analysis discovered that the shear strength of bubble slab went down rapidly beside the loose girder and due to the increased distant of load to support as compared to the normal one.

Nielsen (2006) [8] performed an experimental program on the punching shear capacity of bubbled slab with a thickness of (230 and 450) mm. The results show that the crack mode is like the solid slab and therefore the mean experiments value of the punching shear strength of the bubbled slabs is about (90%) of the normal one.

John and Tomas in (2007) [9] studied the shear strength of two-way bubbled slab. It was cast bubbled slab with 130 mm thickness and a/d ratio of (2.3) and the compared to the solid slab. It was observed that the mean shear capacity was about (76%) of the normal one.

Mutashar in (2016) [10] tested ten one-way slabs (two solid, four bubbled and four hollow core slabs) having the dimensions of (1700 length, 416 width and 100 or 125 thickness) mm.The results show that due to the presence of voids in bubble and hollow core slabs, the self-weight is reduced to 82% and 57% respectively of solid slab and the deflection of bubble and hollow core slabs is larger than a solid slab by (41% and 47% respectively).

2. Research Significance

The significance of this research is to investigate experimentally the shear strength behavior of SCC one-way bubble deck slab. Two types of slabs were studied in this investigation: the first one made by using plastic balls of (73, 60) mm diameter known as bubble deck slab and the other conventional solid slab (without balls) is used as a reference. Many variables were considered in this study such as ball diameter (73,60) mm, shear reinforcement ratio, and spacing between balls.

3. Experimental Program

Thirteen one-way slabs of (1700 length, 700 width and 150 thick) mm were cast and tested to ensure all the slabs fail in shear first. All specimens were designed to fail in on way shear and according to (ACI 318M-14) [11]. The main variables studied are the type of slab (bubble and solid slabs), ball dimeter (73, 60) mm, shear reinforcement and spacing between balls. Details of these parameters are shown in the table 2. The RC slabs were experimented as simply supported slabs under two-point loads. Figures 1a, b, c, d, e, f, 2a, b and 3 show the geometry and dimensions of the bubbled slabs also Plate 1 and Plate 2 shows reinforcement details. Self-compacting concrete with cylinder compressive strength of (39.3) MPa were designed according to (EFNARC, 2005) [12], is used for casting the specimens, the mix proportions and test result are shown in table 1 and 2.

Table 1 Details of SCC mix.

Slump flow (520-900) mm	V-funnel H_2/H_1 (7-27) sec	L-box (0.75-1)	f_c' at 28 days [cylinder] (MPa)
660	13	1	39.3

Table 2 Test result of SCC mix.

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Silica fume% by weight	Water L/m^3	SP% by weight of Cementous material	w/cm
400	798	767	7.5	150	1.8	0.38

Table 3 Description and Details of Slab Specimens.

Group	Specimens symbol	Thickness H (mm)	Effective depth d (mm)	a (mm)	a/d	Ball dimeter (mm)	Spacing between balls (mm)	Longitudinal reinforcement	P_L%	Shear reinforcement (A_v)	Type of Shear reinforcement	ρ_v%
G1	S	150	120	324	2.7	N/A	N/A	16∅10	0.014	N/A	N/A	N/A
G2	S1	150	120	324	2.7	60	Large (5 balls)	16∅10	0.014	N/A	N/A	N/A
	S2	150	120	324	2.7	60	Normal (7 balls)	16∅10	0.014	N/A	N/A	N/A
G3	S1	150	120	324	2.7	73	Large (5 balls)	16∅10	0.014	N/A	N/A	N/A
	S2	150	120	324	2.7	73	Normal (7 balls)	16∅10	0.014	N/A	N/A	N/A
G4	S1	150	120	324	2.7	60	Large (5 balls)	16∅10	0.014	6∅6	Multiple-leg stirrups	0.002
	S2	150	120	324	2.7	60	Normal (7 balls)	16∅10	0.014	6∅6		0.002
	S3	150	120	324	2.7	60	Large (5 balls)	16∅10	0.014	6∅8		0.003
	S4	150	120	324	2.7	60	Normal (7 balls)	16∅10	0.014	6∅8		0.003
G5	S1	150	120	324	2.7	73	Large (5 balls)	16∅10	0.014	6∅6	Multiple-leg stirrups	0.002
	S2	150	120	324	2.7	73	Normal (7 balls)	16∅10	0.014	6∅6		0.002
	S3	150	120	324	2.7	73	Large (5 balls)	16∅10	0.014	6∅8		0.003
	S4	150	120	324	2.7	73	Normal (7 balls)	16∅10	0.014	6∅8		0.003

Length (L) = (1573) mm, Width (b) = (700) mm, L/b = 2.2.
a = shear span, a/d = Shear span to depth ratio.
P_L% = Longitudinal reinforcement ratio, ρ_v% = Shear reinforcement ratio.
for H = (150) mm, Clear Cover = (20) mm, N/A = Not available.
Clear spacing between balls = Greater than bubble diameter/9 according to DIN 1045-1.

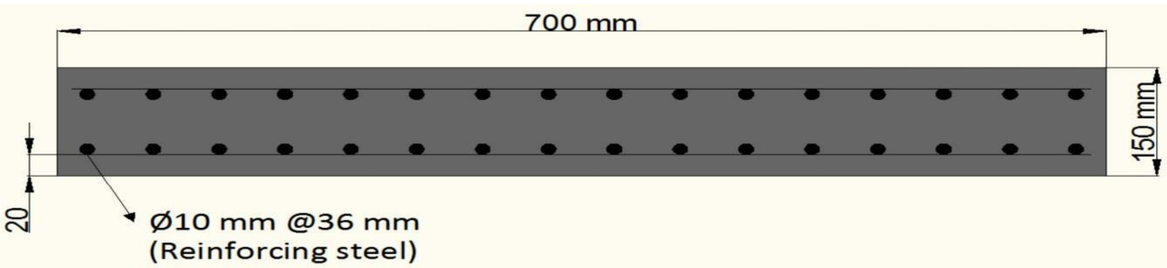

Figure 1a Cross–Section in Solid RC Slab

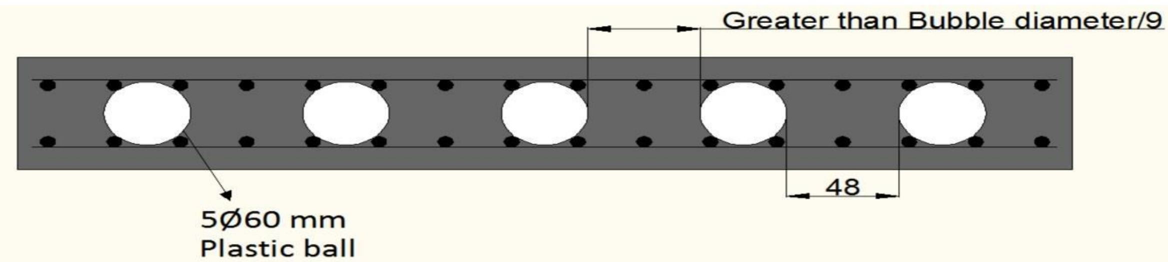

Figure 1b Cross–Section in Bubbled RC Slab with 5Ø60 mm @ 48 mm spacing between balls

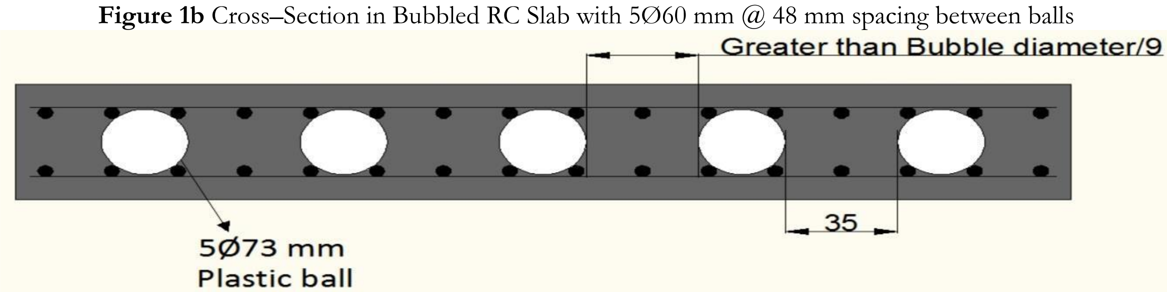

Figure 1c Cross–Section in Bubbled RC Slab with 5Ø73 mm @ 35 mm spacing between balls

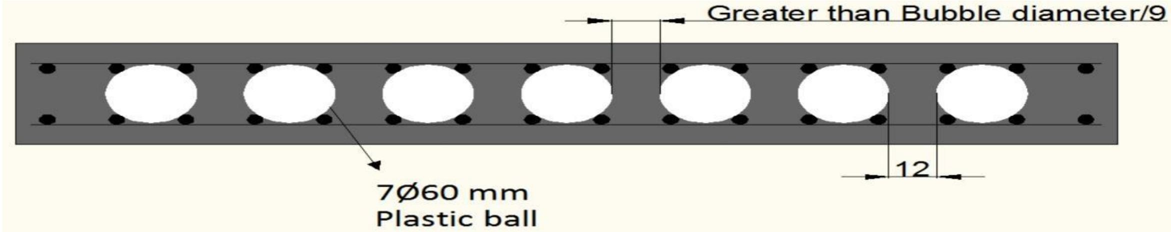

Figure 1d Cross–Section in Bubbled RC Slab with 7Ø60 mm @ 12 mm spacing between balls

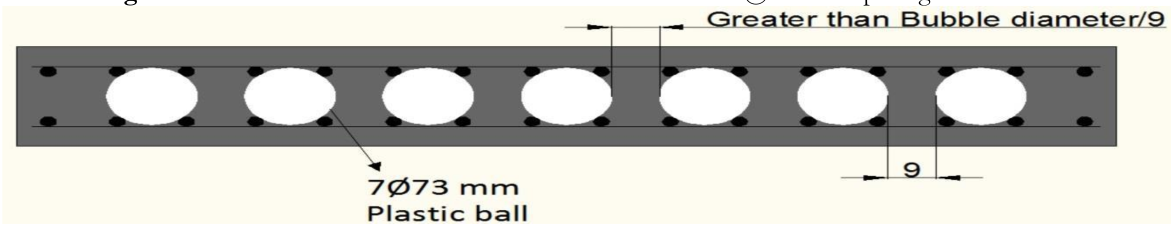

Figure 1e Cross–Section in Bubbled RC Slab with 7Ø73 mm @ 9 mm spacing between balls

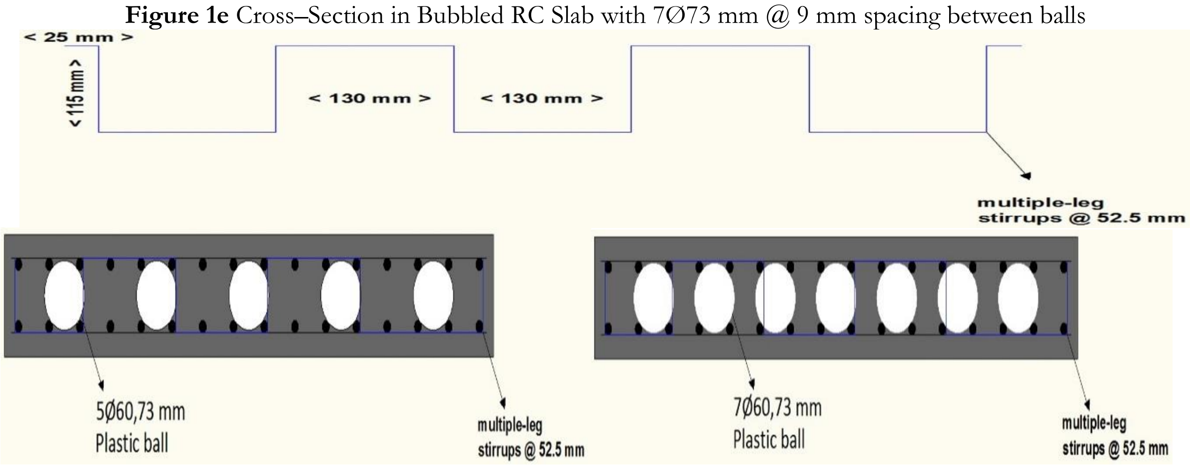

Figure 1f Cross–Section in Bubbled RC Slab with multiple-leg stirrups

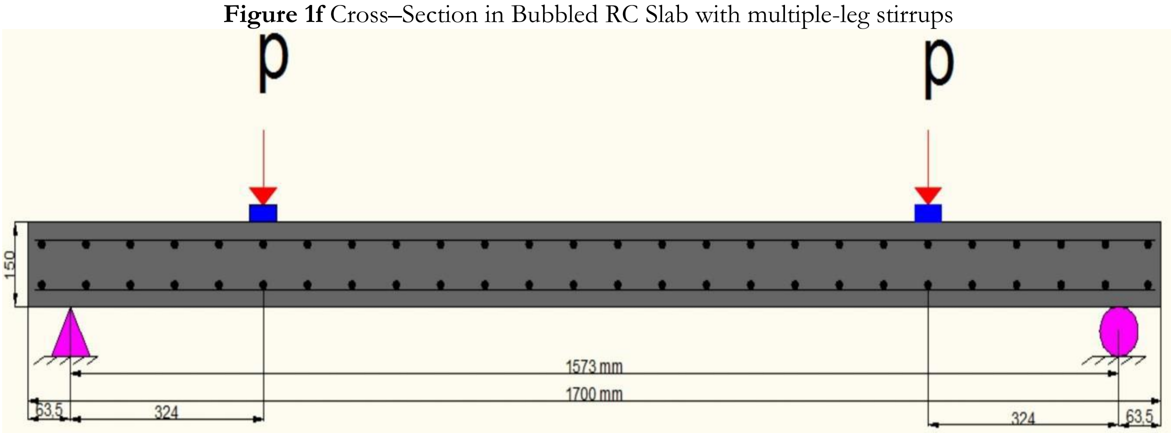

Figure 2a Cross–Section in Solid RC Slab

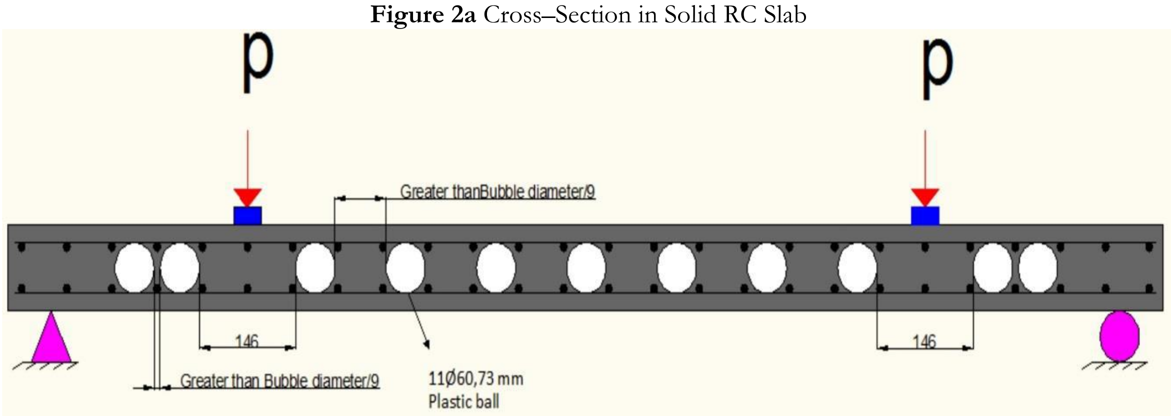

Figure 2b Cross–Section in Bubbled RC Slab

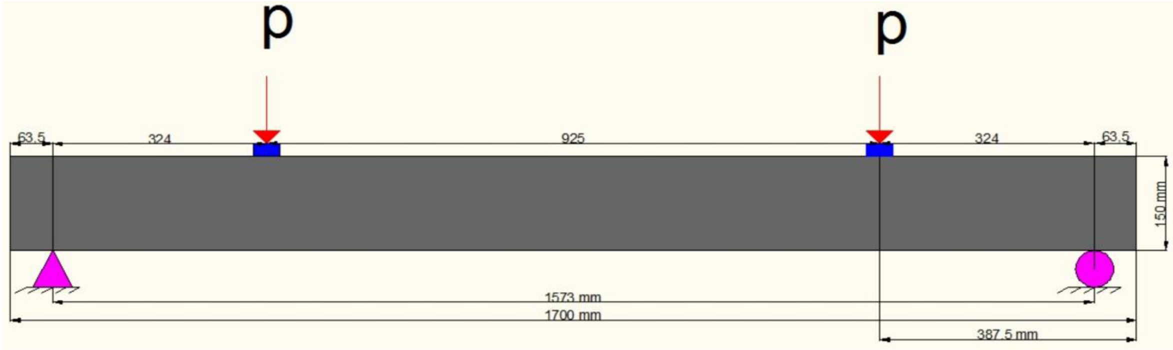

Figure 3 Two-Dimensional View of RC Bubble Slab

Plate 1 Solid Slab with Top and Bottom Steel Mesh

Plate 2 Bubble Slab with Top and Bottom Steel Mesh

Plate 3 Bubble Slab with Shear Reinforcement (multi-leg)

4. Curing Procedure

Curing means that specimens kept in the water in laboratory climate until the age of 28 days. At the end of the curing period, all specimens were removed from the water and kept in the laboratory until the date of testing.

5. Testing Setup

A hydraulic machine is used in the tests with (200) KN capacity. The slabs tested as simply supported under two-line load with a clear three span of which is kept constant for all the slabs. The specimens are supported on steel rollers (50) mm diameter. The load is distributed to the two-line loading by using two steel plates (40 thickness, 80 width and 750 length) mm which are placed on the top surface of the slab at both loading points to prevent local crushing of the concrete, as shown in the plate 4.

Plate 4 Preparation of Testing Slab Specimens

6. Experimental Results

6.1 General Behavior

The test results show that the presence of balls in bubbled slabs leads to a decrease in the flexural stiffness and shear resistance compared to solid slabs. When the clear spacing between balls in cross section is decreased, the reduction in the concrete volume increases and this leads to a decrease in the flexural stiffness and shear resistance of bubbled slabs. The presence of shear reinforcement (multi-leg) in bubbled slabs is so important due to its role in linking the two layers which increase shear dowel actions, lead to improves the bond between the two layers and this increases the ultimate load and first crack load and increases the ultimate deflection.

The general behavior of one-way slabs failing in shear and mode of failure that occurs depends mainly on the a/d ratio. Diagonal shear failure generally occurs when this ratio is between 2.0 and 3.0. Shear failures usually occur with the formation of inclined cracks that resulted from combined bending and shearing stresses. Inclined cracking produces a redistribution of internal stresses which may cause diagonal shear failure.

6.2 Crack Pattern and Mode of Failure

The common cracking pattern as well as the behavior of all slab were similar having the same a/d ratio (2.7) and failing in shear, and diagonal tension failure here is the mode of failure. The mode of failure as well as crack patterns of the tested slabs without shear reinforcement are shown in plates 5, 6, 7, 8 and 9, while the mode of failure as well as crack patterns of the tested slabs with shear reinforcement are shown in plates 10, 11, 12, 13, 14, 15, 16 and 17. Table 4 shows the results of these groups. For the slabs without shear reinforcement the first crack appears at 57.6%, 50.7%, 42.7%, 44.2% and 38.8% of the ultimate load of slabs (G1-S, G2-S1, G2-S2, G3-S1 and G3-S2) respectively. As shown in table 4, the bubbled slabs (G2-S1, G2-S2, G3-S1 and G3-S2) have a decrease in the first crack load when compared with the solid slab by about 15.3%, 31.1%, 28.8% and 42.4% respectively. This is assigned to the presence of the plastic balls which reduces the concrete volumes in the tension zone. The bubbled slabs (G3-S1 and G3-S2) have a decrease in the first crack load when compared with the bubbled slabs (G2-S1 and G2-S2) by about 16% and 16.5% respectively. Also, it can be noted from these results that the first crack load of the clear spacing between balls show that changing the clear spacing in the cross section of bubbled slabs from (12) mm (G2-S2) to (48) mm (G2-S1), increases the first crack load by about 22.9%, and changing the clear spacing in the cross section of bubbled slabs from (9) mm (G3-S2) to (35) mm (G3-S1), increases the first crack load by about 23.5%. And for the slabs with shear reinforcement the first crack appears at 57.6%, 38.9%, 34.1%, 35.6%, 32%, 37.5%, 30.9%, 35.3% and 30.3% of the ultimate load of slabs (G1-S, G4-S1, G4-S2, G4-S3, G4-S4, G5-S1, G5-S2, G5-S3 and G5-S4) respectively. As shown in table 4, the bubbled slabs (G4-S1, G4-S2, G4-S3, G4-S4, G5-S1, G5-S2, G5-S3 and G5-S4) have a decrease in the first crack load when compared with the solid slab by about 5.3%, 17.6%, 2.8%, 14.8%, 9.9%, 27.4%, 6.7% and 22.4% respectively. This is assigned to the presence of the plastic balls which reduces the concrete volumes in the tension zone. The bubbled slabs (G4-S1 and G4-S2) have a decrease in the first crack load when compared with the bubbled slabs (G4-S3 and G4-S4) by about 2.5% and 3.3% respectively, and the bubbled slabs (G5-S1 and G5-S2) have a decrease in the first crack load when compared with the bubbled slabs (G5-S3 and G5-S4) by about 3.4% and 6.5% respectively. Also, it can be noted from these results that the first crack load of the clear spacing between balls show that changing the clear spacing in the cross section of bubbled slabs from (12) mm (G4-S2 and G4-S4) to (48) mm (G4-S1 and G4-S3), increases the first crack load by about 15% and 14.1% respectively, and changing the clear spacing in the cross section of bubbled slabs from (9) mm (G5-S2 and G5-S4) to (35) mm (G5-S1 and G5-S3), increases the first crack load by about 24.2% and 20.3% respectively.

Table 4 Experimental Results for the Slabs

Group	Specimens symbol	First Cracking Load (P_{cr}) (KN)	Deflection at Cracking Load (Δ_{cr}) (mm)	Ultimate Load (P_{ul}) (KN)	Deflection at Ultimate Load (Δ_{ul}) (mm)	Shear at first diagonal crack (V_{cr}) (kN)	Shear at Ultimate load (V_u) (kN)	Diagonal crack angle (θ) (Degree)
G1	S	200.8	12.5	348.4	19.5	100.4	174.2	60
G2	S1	170.1	14.7	335.4	21.4	85.1	167.7	55
	S2	138.5	15.8	324	22.6	69.3	162	56
G3	S1	142.9	15.6	323.5	22.2	71.5	161.8	40
	S2	115.7	17	298.5	23.7	57.9	149.3	45
G4	S1	190.2	12.9	488.7	19.8	95.1	244.4	59
	S2	165.4	15	484.7	22.1	82.7	242.4	57
	S3	195.1	12.7	548	19.6	97.6	274	56
	S4	171	14.8	534	21.7	85.5	267	50
G5	S1	181	13.9	482.3	20.7	90.5	241.2	46
	S2	145.7	15.5	471.6	22.4	72.9	235.8	49
	S3	187.4	13.7	531.4	20.4	93.7	265.7	48
	S4	155.8	15.3	515.1	21.9	77.9	257.6	47

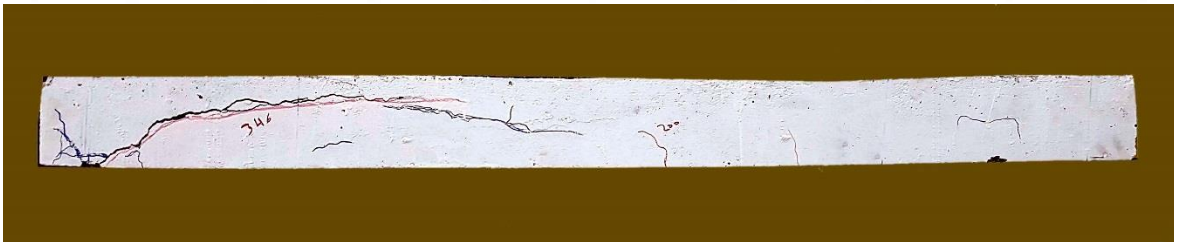

Plate 5 Crack pattern and mode of failure of solid slab (G1-S)

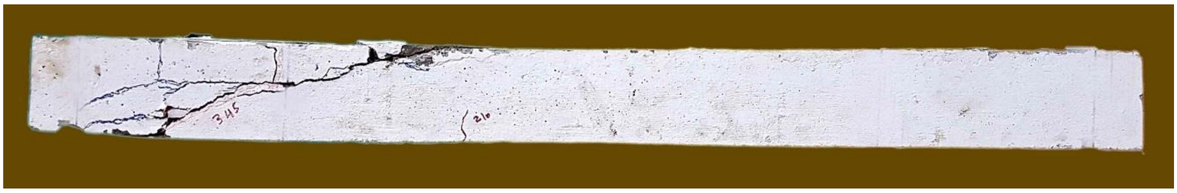

Plate 6 Crack pattern and mode of failure of bubbled slab (G2-S1)

Plate 7 Crack pattern and mode of failure of bubbled slab (G2-S2)

Plate 8 Crack pattern and mode of failure of bubbled slab (G3-S1)

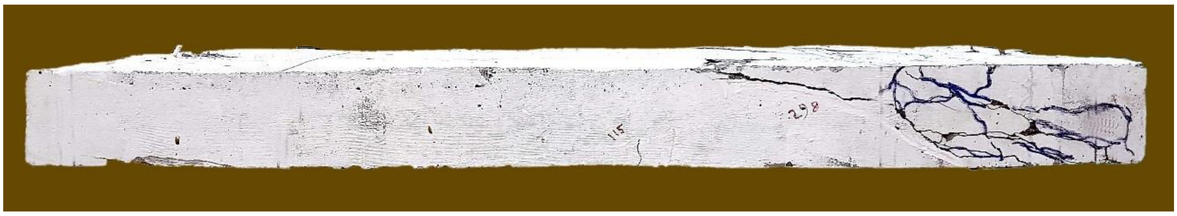

Plate 9 Crack pattern and mode of failure of bubbled slab (G3-S2)

Plate 10 Crack pattern and mode of failure of bubbled slab (G4-S1)

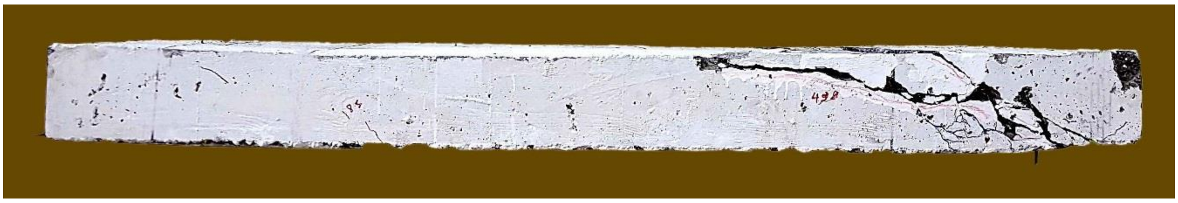

Plate 11 Crack pattern and mode of failure of bubbled slab (G4-S2)

Plate 12 Crack pattern and mode of failure of bubbled slab (G4-S3)

Plate 13 Crack pattern and mode of failure of bubbled slab (G4-S4)

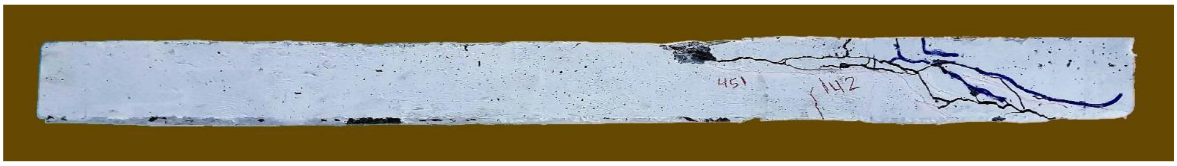

Plate 14 Crack pattern and mode of failure of bubbled slab (G5-S1)

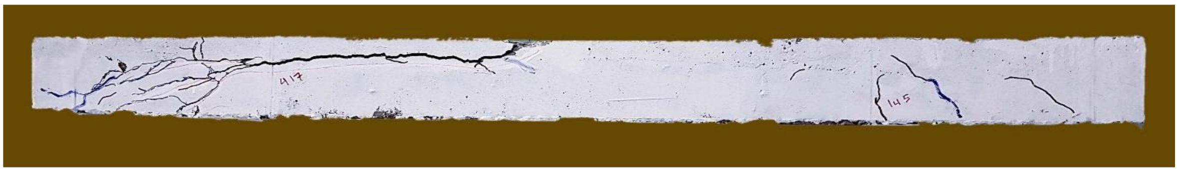

Plate 15 Crack pattern and mode of failure of bubbled slab (G5-S2)

Plate 16 Crack pattern and mode of failure of bubbled slab (G5-S3)

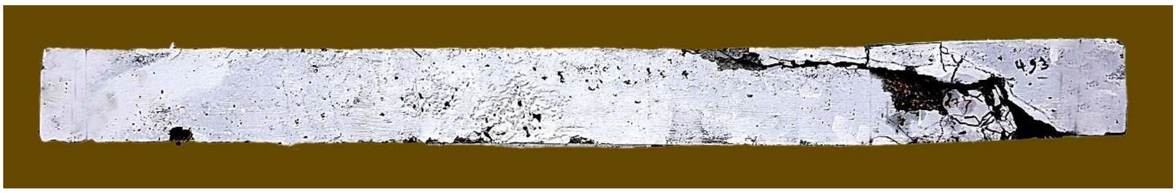

Plate 17 Crack pattern and mode of failure of bubbled slab (G5-S4)

6.3 Ultimate Load

The results of the tested slabs are listed in table 3. The slabs without shear reinforcement there is a reduction in the ultimate loads of the bubbled slabs (G2-S1, G2-S2, G3-S1 and G3-S2) as compared with the solid slab by about 3.7%, 7%, 7.2% and 14.3% respectively. The value of this reduction is attributed to the presence of the plastic balls which are placed at the core of the bubbled slabs sections where the stress is minimum. Also, it can be noted from these results that the ultimate loads of the clear spacing between balls show that changing the clear spacing in the cross section of bubbled slabs from (12) mm (G2-S2) to (48) mm (G2-S1), increases the ultimate load by about 3.5%, and changing the clear spacing in the cross section of bubbled slabs from (9) mm (G3-S2) to (35) mm (G3-S1), increases the ultimate load by about 8.4%. This increase in the ultimate loads is ascribed to the amount of reduced concrete which becomes smaller when the clear spacing gets larger so that the slabs (G2-S1 and G3-S1) maintain higher percentage of ultimate load in comparison with those having smaller clear spacing (G2-S2 and G3-S2). Furthermore, the bubbled slabs (G2-S1 and G2-S2) have better load carrying capacity than bubbled slabs (G3-S1 and G3-S2) by about 3.7% and 8.5% respectively.The slabs with shear reinforcement these results show there is an increase in the ultimate loads of the bubbled slabs (G4-S1, G4-S2, G4-S3, G4-S4, G5-S1, G5-S2, G5-S3 and G5-S4) as compared with the solid slab by about 40.3%, 39.1%, 57.3%, 53.3%, 38.4%, 35.4%, 52.5% and 47.8% respectively. The value of this increase is attributed to the presence of the shear reinforcement (multi-leg) in bubbled slabs. Also, it can be noted from these results that the ultimate loads of the clear spacing between balls show that changing the clear spacing in the cross section of bubbled slabs from (12) mm (G4-S2 and G4-S4) to (48) mm (G4-S1 and G4-S3), increases the ultimate load by about 0.8% and 2.6% respectively, and changing the clear spacing in the cross section of bubbled slabs from (9) mm (G5-S2 and G5-S4) to (35) mm (G5-S1 and G5-S3), increases the ultimate load by about 2.3% and 3.2% respectively. Furthermore, the bubbled slabs (G4-S1, G4-S2, G4-S3 and G4-S4) have better load carrying capacity than bubbled slabs (G5-S1, G5-S2, G5-S3 and G5-S4) by about 1.3%, 2.8%, 3.1% and 3.7% respectively.

6.4 Deflection and Load Capacity

Figure 4 show the experimental load-deflection curves of tested slabs without shear reinforcement, Figure 5 show the experimental load-deflection curves of tested slabs with shear reinforcement. Table 5 shows the values of load and deflection. For the slabs without shear reinforcement table 5 show that at ultimate load the corresponding deflections of the bubbled slabs (G2-S1, G2-S2, G3-S1 and G3-S2) are more than that of the solid slab by 10%, 16%, 14% and 22% respectively, this results due to decrease in the moment of inertia of bubble slabs compare with solid slab. Also, the results show that changing the clear spacing in the cross section of bubbled slabs from (48) mm (G2-S1) to (12) mm (G2-S2), increases the deflection at ultimate load by about 6%, and changing the clear spacing in the cross section of bubbled slabs from (35) mm (G3-S1) to (9) mm (G3-S2), increases the deflection at ultimate load by about 7%. Also, the results show that at ultimate load the deflections of the bubbled slabs (G3-S1 and G3-S2) are more than that of the bubbled slabs (G2-S1 and G2-S2) by 4% and 5% respectively**.** And for the slabs with shear reinforcement table 3 show that at ultimate load the corresponding deflections of the bubbled slabs (G4-S1, G4-S2, G4-S3, G4-S4, G5-S1, G5-S2, G5-S3 and G5-S4) are more than that of the solid slab by 2%, 13%, 1%, 11%, 6%, 15%, 5% and 12% respectively, this results due to decrease in the moment of inertia of bubble slabs compare with solid slab. Also, the results show that changing the clear spacing in the cross section of bubbled slabs from (48) mm (G4-S1) to (12) mm (G4-S2), increases the deflection at ultimate load by about 12%, and the results show that changing the clear spacing in the cross section of bubbled slabs from (48) mm (G4-S3) to (12) mm (G4-S4), increases the deflection at ultimate load by about 11%, and changing the clear spacing in the cross section of bubbled slabs from (35) mm (G5-S1) to (9) mm (G5-S2), increases the deflection at ultimate load by about 8%, and changing the clear spacing in the cross section of bubbled slabs from (35) mm (G5-S3) to (9) mm (G5-S4), increases the deflection at ultimate load by about 7%. Also, the results show that at ultimate load, the deflection of the bubbled slab (G4-S1) are more than that of the bubbled slab (G4-S3) by 1%**,** and the deflection of the bubbled slab (G4-S2) are more than that of the bubbled slab (G4-S4) by 2%, and the deflection of the bubbled slab (G5-S1) are more than that of the bubbled slab (G5-S3) by 2%**,** and the deflection of the bubbled slab (G5-S2) are more than that of the bubbled slab (G5-S4) by 2%. Also, the results show that at ultimate load, the deflection of the bubbled slabs (G4-S1 and G4-S3) are less than that of the bubbled slabs (G5-S1 and G5-S3) by 4% and 4% respectively**,** and the deflection of the bubbled slabs (G4-S2 and G4-S4) are less than that of the bubbled slabs (G5-S2 and G5-S4) by 1% and 1% respectively.

Table 5 Deflection of First and Ultimate Cracking Load

Group	Specimens symbol	First Cracking Load (P_{cr}) (KN)	Deflection at Cracking Load (Δ_{cr}) (mm)	Ultimate Load (P_{ul}) (KN)	Deflection at Ultimate Load (Δ_{ul}) (mm)
G1	S	200.8	12.5	348.4	19.5
G2	S1 S2	170.1 138.5	14.7 15.8	335.4 324	21.4 22.6
G3	S1 S2	142.9 115.7	15.6 17	323.5 298.5	22.2 23.7
G4	S1 S2 S3 S4	190.2 165.4 195.1 171	12.9 15 12.7 14.8	488.7 484.7 548 534	19.8 22.1 19.6 21.7
G5	S1 S2 S3 S4	181 145.7 187.4 155.8	13.9 15.5 13.7 15.3	482.3 471.6 531.4 515.1	20.7 22.4 20.4 21.9

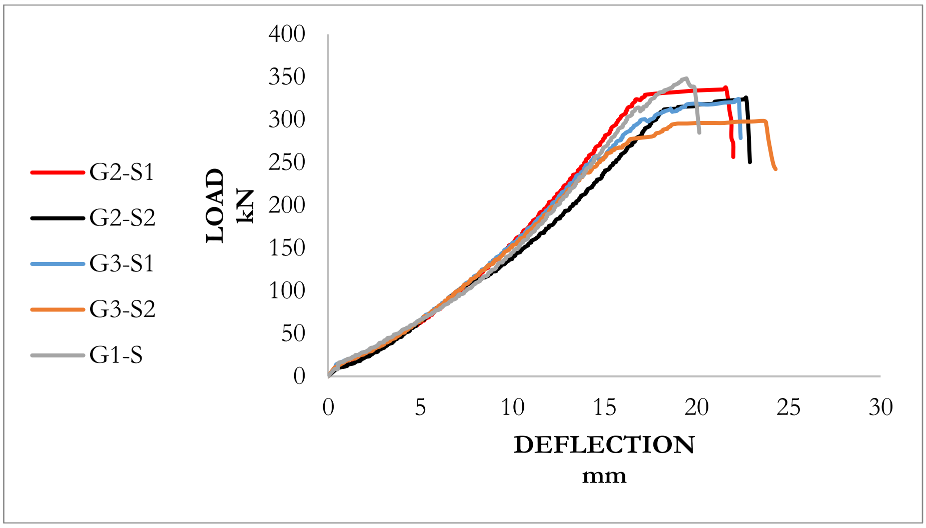

Figure 4 Load-Deflection Behavior for the Slabs in Groups 1, 2 and 3 without Shear Reinforcement

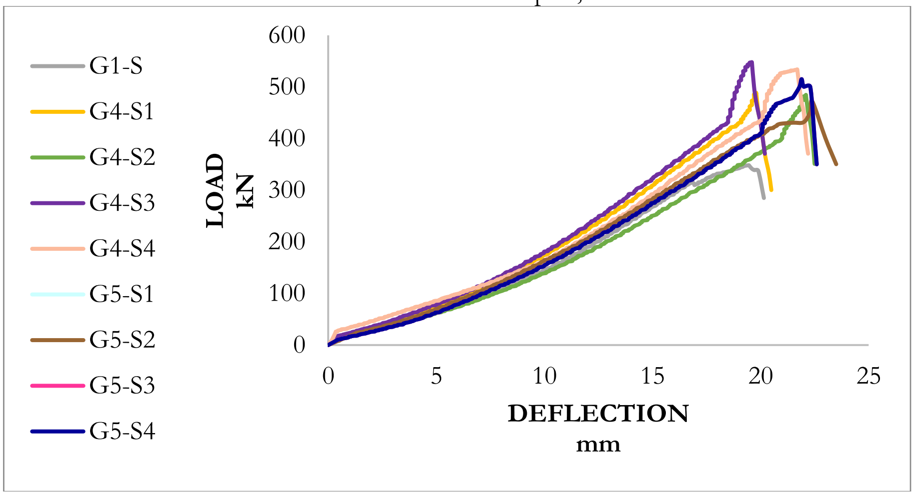

Figure 5 Load-Deflection Behavior for the Slabs in Groups 1, 4 and 5

7. Conclusions

The following conclusions can be listed as follows:

1. All the tested slabs specimens with and without shear reinforcement failed in shear and mode of failure was diagonal shear failure, also sudden shear failure was happened when the dominant diagonal

shear cracks formed in one or two side of the shear span.

2. The deflection at cracking load (Δcr) and ultimate load (Δul) for all bubbled slabs is more than that in the solid slab.

3. Increasing the clear spacing between (60) mm diameter balls for all bubbled slabs in groups 2 and 4 from (12) mm to (48) mm give an increase in the ultimate load and the first crack load, and a decrease in the ultimate deflection. While increasing the clear spacing between (73) mm diameter balls for all bubbled slabs in groups 3 and 5 from (9) mm to (35) mm give an increase in the ultimate load and the first crack load, and a decrease in the ultimate deflection

4. The use of (73) mm diameter balls instead of (60) mm diameter balls in all groups of bubbled slabs shows a decrease in the ultimate load and the first crack load, and an increase in the ultimate deflection.

5. Use of multiple-leg shear reinforcement in bubbled slabs in groups 4 and 5 improves the bond between the two layers. Based on this improvement, the ultimate load and the first crack load of these groups are more than bubbled slabs without shear reinforcement in groups 2 and 3, and the ultimate deflection is less.

6. There is a decrease in the first crack load of all bubbled slabs when compared with that of the solid slab.

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